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Long-term suspended sediment transport in the Goodwater Creek Experimental Watershed and Salt River Basin, Missouri, USA

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[1] Since 1992, efforts have been conducted in Goodwater Creek Experimental Watershed to assess suspended sediment transport from this 73 km^2 watershed located in the Salt River Basin, Missouri, USA. This effort was complemented by assessment of field-scale sediment loss and of suspended sediment transport at 12 watersheds in the Salt River Basin. The database includes 10 to 20 years of data from 3 fields ranging from 7 to 35 ha, and 5 to 20 years of data from 15 stream sites ranging from 10 to 6200 km^2. Sampling techniques, analytical methods, site locations, and equipment infrastructure are described in this paper.

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1. Introduction

[2] Soil erosion represents perhaps the most telling impact of agriculture on the American landscape. Choices of cropping and tillage systems have impacts on crop yields, surface runoff, and soil loss, as well as nutrient and chemical losses. However, soil erosion provides the most direct feedback to agricultural producers on the sustainability of their management because, unlike runoff, nutrient or chemical losses, severe soil loss is often visible after a large event. Deep rills can be seen in the fields, deposited sediment can be seen in flatter areas, and eroded stream banks look distinctly different from well protected ones. Even though erosion effects can be seen after a single event, the magnitude of soil loss and its impact on productivity and sustainability can only be documented over a long period, through long-term monitoring.

[3] Claypan soils represent a specific extreme case of hydrologic conditions in the Midwest agricultural landscape. Claypan soils and other similar soils include a restrictive layer of very low permeability that limits percolation through the soil profile, which leads to high runoff potential. High runoff, in turn, leads to high soil erosion and sediment transport on agricultural land that has little ground protection. The Goodwater Creek Experimental Watershed (GCEW) was established in 1970 with the purpose of understanding runoff generation and flow transport on claypan soils. In 1992, water quality monitoring, including suspended sediment, hereafter referred to as sediment, was initiated. In 2005, additional flow and water quality monitoring stations were established on all the tributaries of the Salt River, to document flow routing and chemical and sediment transport in the Salt River Basin. This article documents sediment data collected at field and watershed scales in GCEW and in the Salt River Basin.

2. Data Collection

2.1. Sites and Data Collection

[4] Three nested watersheds (12, 35, and 73 km^2) were instrumented in 1971 with V-notch weirs (Weir 11, Weir 9, and Weir 1, respectively, see Figure S1 in supporting information section S1) and flow monitoring equipment. Continuous sediment transport monitoring started in 1992 when the three weirs were instrumented with automatic samplers to collect flow weighted water samples. Automatic samplers were also installed in 1992 at the outlet of three fields (Field 1, Field 2, and Field 3) where flow-weighted samples were collected until 2002 for Field 2 and Field 3 and until present for Field 1. The above efforts were complemented by larger scale monitoring efforts in 2005. Auto samplers were installed on Young's Creek and Long Branch, downstream of the three existing Goodwater Creek stream weirs, and on the Upper Long Branch where the drainage area is comparable in size to that of Young's Creek (Figure S2 in supporting information section S1). In addition, eight other tributaries of Mark Twain Lake in the Salt River Basin were instrumented with auto samplers for flow-weighted, point sampling during events. Grab samples were collected every other week downstream of Mark Twain Lake but no auto sampler was installed there because the dam completely regulates the flow and the concept of storm events doesn't apply for this site. The complete suite of

Additional supporting information may be found in the online version of this article.

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instrumentation provides documentation of sediment transport at scales ranging from 8 ha to 1,182 km^2. Table S1 in supporting information section S1 provides sampling site locations and sizes of the drainage areas. Other details on sampling protocols and auto-sampler programming parameters are given in supporting information section S2.

[5] At the field scale, samples were collected during each event throughout the year and brought to the laboratory within 48 h of the event's end. A grab sample was also collected each time the site was serviced if flow was running. The stream weirs in GCEW were also serviced after each event, supplemented by weekly grab samples. At the larger scale in the Mark Twain Lake tributaries, composite samples were collected for each event from early spring to late fall and grab samples were collected year round every other week. A total of 2134 samples from the three Goodwater Creek sites were collected from 1993 to 2010. In addition, 2989 field samples were collected from 1993 to 2010, and 2244 samples were collected from the Mark Twain Lake tributaries from 2005 to 2010.

2.2. Sample Analyses and Data Reduction

[6] Upon arrival in the laboratory, samples were divided into subsamples for chemical and sediment analyses and electronic records of the samples were created as explained in supporting information section S3. Until March 2009, sediment subsamples were processed using the evaporation method [*Brakensiek et al.*, 1979] in which samples are allowed to settle undisturbed after which excess liquid is decanted from the top of the sample. The remainder was transferred to an evaporating dish, oven-dried, and weighed. Starting in April 2009, the filtration method [*Brakensiek et al.*, 1979] was used. In this method, samples were analyzed for sediment within one day of arrival to the lab. A subsample was pipetted and filtered through a previously weighed dried filter, which was then oven-dried and reweighed for sediment concentration determination. From April 2009 to February 2010, both methods were used concurrently and results were compared. Section 4.1 in supporting information section S4 describes the results of this test, which indicated that the methods were comparable over all analyses, and particularly so for sediment concentrations >100 mg/L.

[7] From 1992 to March 2009 and from March 2010 to December 2010, samples that appeared clear were not analyzed for sediment; these included 70% and 93% of the grab samples from the fields and GCEW, respectively. From April 2009 to February 2010, all samples were analyzed, whether they appeared clear or not. Measured sediment concentrations in the grab samples collected during that period averaged 34 and 17 mg/L at Weir 1 and Field 1, respectively. We later describe the effect that the assumed sediment concentration of clear samples, i.e., zero or these averages, had on annual transport.

[8] Once sediment concentrations were obtained, sediment load calculations were performed. Concentrations were interpolated between measured values as explained in supporting information section S3. Loads were then calculated from the concentrations and corresponding discharge values for each sample in case of multiple samples collected during a day, or for each day in case of a single concentration value available for that day.

3. Quality Analysis

3.1. Storm Flow Sediment Concentration

[9] From time to time, concentration values were missing in auto-samples. Reasons included malfunctions of the sampling equipment, low volume of the collected sample, and lost, dropped or spilled samples. In the database, flags indicate the nature of these problems.

[10] At times, samples did not have enough water to conduct all the analyses requested by the protocol. In that case, priority went first to herbicides, then to nutrients, then to sediment. Because of these priorities, some auto-samples were not analyzed for sediment. These occurrences became less frequent over time because herbicide and nutrient analytical methods have switched to some that require a lower water volume. Other conditions have occasionally led to auto-samples not being analyzed, e.g., lost or broken samples and flooded conditions that prevented access to the site. All causes together, and including samples that appeared clear, about 12%, 23%, and 17% of the field, Goodwater Creek stream and Mark Twain Lake tributaries auto samples were not analyzed. Years during which a large (>15) number of auto samples were not analyzed at Weir 1 were 1995, 1996, and 1999.

[11] Equipment malfunctions included those of the flow meter and of the sampler, which led to no sample being collected when one should have been. In most cases, the site was accessible and a grab sample was collected at the time of the visit; in a few cases, e.g., 2008, the site was not accessible and no concentration data were available. These occurrences were more frequent at the beginning of the monitoring period in the early 1990s. Later, the longest malfunction occurred during the summer of 2000 (57 days) and included one intense rain event.

3.2. Base Flow Sediment Concentration

[12] Base flow represents a small fraction of total flow in these claypan soil watersheds and the contribution of base flow to the annual sediment loads is even smaller. In the fields, there was no base flow but grab samples were collected each time the site was serviced at the end of an event. These samples were usually very clear. Based on the average concentration of 17 mg/L in these end-of-event samples collected at Field 1 in 2009 and 2010, the corresponding average annual sediment load represents 0.1% of the average annual sediment load at that site. The assumption that clear samples were free of sediment was therefore acceptable.

[13] At the stream weirs, the larger proportion of base flow relative to total flow makes the influence of base flow sediment concentrations more pronounced. Base flow is defined here as the dry weather flow between events. This was especially true during dry years, as in 1996 or 2000 for example. Table S4 in supporting information section S4 shows the 1993–2010 annual loads at Weir 1 assuming base flow concentrations of 0 and 34 mg/L. The largest relative sediment load differences between these two assumptions occurred in 1996 and 2000, the two driest years over the 1993–2010 monitoring period. During other years, which were characterized by larger flows, the relative differences were less than 3.3% in any year, and less than 2% on average. While the difference in 2000 was much higher,

Table 1. Average Annual or Seasonal Unit Area Suspended Sediment Loadings in the Salt River Basin

Site	Station ID	Period Used in the Average	Drainage Area (km^2)	Average Unit Area Loading (kg ha^{-1} year^{-1}) or (kg ha^{-1} season^{-1})
Year-Round Sites				
Field 1	MOGC0291	1993–2001	0.344	4361
Field 2	MOGC0292	1993–2001	0.078	1105
Field 3	MOGC0293	1993–2001	0.073	1465
GCEW Weir 11	MOGC0296	1993–1996	12.1	2022
GCEW Weir 9	MOGC0297	1993–1996	30.6	1731
GCEW Weir 1	MOGC0298	1993–2010	72.9	1825
Seasonal Sites April–October				
Young's Creek	MOYC0001	2005–2010	189	1338
Lower Long Branch	MOLL0001	2005–2010	470	1371
Crooked Creek	MOCC0001	2005–2010	212	1601
Elk Fork Salt River	MOEF0001	2005–2010	513	1338
Lick Creek	MOLC0001	2005–2010	269	1543
Middle Fork	MOMF0001	2005–2010	864	1545
North Fork Salt River	MONF0001	2005–2010	1186	2484
South Fork Salt River	MOSF0001	2005–2010	590	1259
Salt River	MOSR0001	2005–2010	6156	77

69%, the load was noticeably low due to the lack of flow. The 465,000 kg annual sediment transport in 2000, assuming 34 mg/L in clear base flow samples, represents only 3% of the average annual sediment load.

4. Data Availability

[14] All flow-weighted storm event and grab sample concentrations and flow data are available for the fields and stream weir sites, from the Sustaining the Earth's Watersheds, Agricultural Research Data System (STEWARDS) (www.ars.usda.gov/watersheds/stewards, accessed 1 June 2012) [*Steiner et al*., 2009; *Sadler et al*., 2008]. Section 5 in supporting information describes how to navigate the site. All data available through STEWARDS are in the public domain, and are not restricted by copyright. Metadata document methods for obtaining these data and successive updates.

5. Example Data

[15] Average annual or seasonal unit area sediment loads, along with the monitoring period used to calculate the average, are presented in Table 1. This data set includes watersheds of varied size ranging from 7.5 ha (Field 2, MOGC0292) to 1,200 km^2 (North Fork, MONF0001). The Upper Long Branch, Black Creek and Otter Creek sites are not included because of uncertainties in the rating curves needed to estimate flow values from measured stage. The watershed of the Salt River encompasses the full drainage area of the lake and is monitored at the outlet of the lake (MOSR0001). However, flow and sediment loads are strongly affected by dam operations and lake processes.

[16] The effect of scale on sediment loss can be studied from two subsets of this data set. On one hand, the three fields and the outlet of Goodwater Creek (Weir 1) were simultaneously monitored from 1993 to 2001, representing an increase in drainage area by 2 and 3 orders of magnitude. Annual loads from the fields are affected by the crop grown each year and the associated field operations. Average monthly loads shown in Figure 1 highlight differences between the edge-of-field soil losses from a corn-soybean tilled field (MOGC0291), two fields with varying no-till management described in supporting information section S6 (MOGC0292 and MOGC0293), and the sediment transported out of the watershed at Weir 1 (MOGC0298). In the fields, tillage and planting operations that occurred from mid-May to mid-June caused increased soil loss in June. That increase is barely seen at the watershed scale, perhaps concealed by the high late-winter sediment transport. Given the absence of field operations before late April in the watershed, possible sources of sediment in late winter and early spring include sheet erosion caused by the lack of ground cover and stream bank erosion, which has been shown to be the major source of in-stream sediment for the Crooked and Otter Creek watersheds [*Willett et al*., 2012].

[17] On the other side of the scale range, Goodwater Creek at Weir 1 (MOGC0298), Young's Creek (MOYC0001), and Lower Long Branch (MOLL0001) were all monitored from April to October from 2006 to 2010 (Figure 2). These watersheds range in size from 73 to 470 km^2, a six-fold increase. All were strongly affected by a July 2008 storm, which was especially intense in the southern half of the Salt River basin. Accordingly, the highest average monthly sediment load for these streams was seen

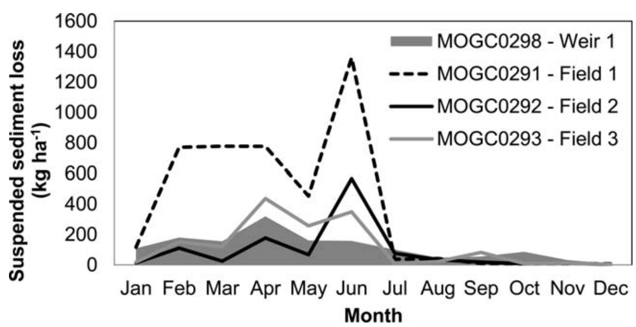

Figure 1. Average monthly unit area sediment loss at the edge of the three instrumented fields and the outlet of GCEW (MOGC0298) from 1993 to 2001. Field 1 is corn-soybean tilled, Field 2 is corn-soybean no-till, and Field 3 is corn-soybean-wheat no-till.

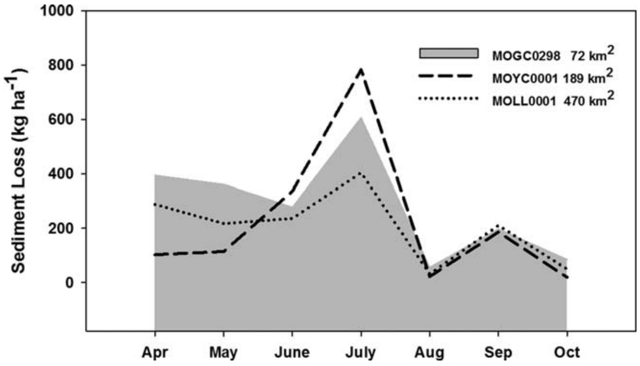

Figure 2. Average monthly unit area sediment loss from GCEW (MOGC0298), Young's Creek (MOYC0001), and the Lower Long Branch (MOLL0001) from 2006 to 2010.

in the month of July, a month where sediment loads would generally be low during a normal year.

6. Overview of Research Based on These Data

[18] *Hjelmfelt and Wang* [1999] used observations of runoff and sediment event data from Field 1 to calibrate a physically based, distributed model based on the St. Venant equation for runoff, and interill and rill detachment for sediment transport. The calibrated model was used to show that placing a grass waterway in the field drainage channel has potential for retarding runoff and reducing sediment loss.

[19] Sediment data series from Field 1 have been supporting recent modeling efforts. *Mudgal et al*. [2012] used data from Field 1 to calibrate and validate the Agricultural Policy Environmental Extender (APEX) model [*Williams et al*., 2008] and develop indices that identify the most vulnerable areas in the field. Additionally, *Mudgal* [2010] calibrated a watershed model with GCEW data and showed that these indices were equivalent to the model for identifying vulnerable areas in GCEW.

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